ARS SPECIAL REPORT

HARVEST-AID CHEMICALS FOR COTTON

Defoliants, Desiccants, and Second-Growth Inhibitors

ARS 22-58

June 1960

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

SUMMARY

This report delineates results of research on the use of chemicals to help prepare cotton for harvesting. It seeks to answer many of the preharvesting questions most often asked by growers and others who are interested in the economical production of high-quality cotton. It discusses problems on which research is incomplete and trends indicated as the result of new investigations.

Research so far reveals that the proper use of harvest-aid chemicals does not reduce fiber quality or adversely affect the milling properties of mature cotton; and that their use may contribute to efficient harvesting, ginning, and insect control, even though yields may be slightly reduced under some conditions.

Research further shows that growers who plan for defoliation usually achieve satisfactory results, that the timing of chemical application is important, that bottom defoliation sometimes contributes to good harvesting and high yields, that controlling late growth and second growth is important, and that additives sometimes make defoliants more efficient.

Information in this report was provided by the Crops Research Division and the Agricultural Engineering Research Division, Agricultural Research Service

HARVEST-AID CHEMICALS FOR COTTON--
Defoliants, Desiccants, and Second-Growth Inhibitors

The advantages that may accrue from the use of chemicals to help condition cotton plants for harvesting are recognized and appreciated wherever cotton is grown in the United States. The chemicals, generally referred to as harvest-aid chemicals, fall into three classes--defoliants that induce the plant to drop (abscise) its leaves but do not kill it; desiccants that kill the leaves and may kill the plant and dry it out; and second-growth inhibitors that prevent the plant from growing new leaves immediately after defoliation. The classifications more or less overlap. Some defoliants can function as desiccants (depending on the amount applied) and some second-growth inhibitors also defoliate.

Interest in these chemicals apparently crystallized during World War II when it was found that mechanical pickers did not work efficiently in rank, leafy cotton. Interest in them has intensified since the War because of these problems: (1) The availability of handpickers continues to decline even in previous areas of plenty; (2) the increased emphasis on higher yields has resulted in a cotton plant that is larger, more leafy, and that matures later than its predecessors--these factors increase the need for harvest conditioning but make it more difficult; and (3) the implication that premature defoliation affects the spinning qualities of cotton.

Growers, facing these problems, or at least aware of them, are asking more and more questions about the chemicals and whether their unqualified use is always advisable. Scientists of the Agricultural Research Service, United States Department of Agriculture, and their cooperators in many State experiment stations throughout the Cotton Belt are seeking answers.

The chemicals are available as either dusts or sprays and can be applied by either airplanes or ground machines with one exception--if it is necessary to defoliate only the bottom part of a plant at a given time, only ground machines and sprays can be used.

Additives sometimes improve defoliant efficiency. The manner in which defoliants and desiccants are used varies in different areas of the Cotton Belt because of differences in climate, type of cotton grown, and management practices.

The number of acres treated with cotton-conditioning chemicals increased from about 2.5 million in 1952 to about 4.7 million in 1958. Since the number of acres in cotton decreased during this span of time from 26 million to about 12 million, the acreage treated in 1958 represents nearly 40 percent of the total cotton acreage in the United States. In 1959, a reported 50 percent of the total cotton acreage was treated with some kind of harvest-aid chemical. Also, the number of acres on which desiccants were used increased from less than 120,000 in 1952 to nearly 1.6 million in 1958. The trend toward the use of more desiccants is increasing.

DEFOLIATION VERSUS DESICCATION

Misuse of the term "defoliation" originated when chemicals applied to kill potato vines before harvest were called defoliants. This error was carried to cotton, and some growers still consider that any chemical that conditions cotton for harvest should be called a defoliant. Actually it is the purpose rather than the chemical that dictates terminology.

Defoliants are used to remove leaves quickly--to cause them to abscise and fall to the ground. Drying is not the purpose nor is it desired. Leaves that are green and moist tend to fall free of the lint in open bolls.

Desiccants are used to dry leaves and other plant parts quickly. Defoliation may or may not result. Most often, fully desiccated leaves are killed and thus lose their ability to abscise by a natural growth process. Eventually, however, wind may break off many of them. If the plant is near a stage of development where natural leaf fall is imminent, the application of desiccants may hasten the process. Generally, however, chemical desiccation causes little or no rapid leaf fall.

Fast, perfect defoliation (100 percent leaf fall in 3 to 5 days) is infinitely preferable to desiccation, but it is not always attainable. Desiccation is, in general, a substitute for defoliation, but it has become the standard where stripper harvesting methods are used (in certain Texas-Oklahoma areas); when conditioning is needed late in the season and defoliants would be ineffective or too slow, where droughty plants fail to react properly to defoliants, and where defoliants would not remove second-growth leaves. The following section explains some of the physiological processes involved when leaves fall off or abscise from a plant.

ABSCISSION AND SENESCENCE

Abscission is the term applied to the vital process that results in a leaf being freed from the plant. It is a natural process in cotton and other deciduous plants and usually occurs at the end of the growing season when the leaf is physiologically mature or relatively senescent.

Senescence or physiological maturity is the state of being old. When the term is applied to cotton plants, it is relative. It has nothing to do with the actual age of the plant or to its comparative size--how big it is in relation to other plants. A cotton leaf is considered senescent when both the external form and the internal structure of the leaf are fully differentiated. At this time the abscission zone at the base of the leaf stalk is also differentiated internally and abscission will be induced quickly when defoliant chemicals are applied under proper conditions.

No infallible outward signs of leaf senescence exist. With progression of leaf maturation, however, a narrow, slightly yellow hyaline line is discernible around the slightly swollen base of the leaf stalk. This line may mark the zone of eventual separation. Leaves exhibiting this line usually snap off cleanly across the zone if the petiole is bent sharply upward. Progressive yellowing of leaves may also indicate senescence.

But yellowing is not a perfect guide because chemicals often defoliate dark green leaves easily and rapidly.

Any action or condition that hastens senescence can also hasten abscission. Certain insect and disease attacks, depletion of nutrients, drought, low light intensity (when plants are crowded) and unfavorably low temperatures fall into this category. Frost is an efficient inducer of abscission, but severe frosts or freezes may kill the cells in which abscission takes place. The result would be dead leaves still on the plant (the action of desiccants) rather than abscissed leaves on the ground. Chemical defoliants merely hasten the natural abscission process--permitting the grower to time leaf fall to suit his harvesting needs.

EFFECTS OF DEFOLIATION AND DESICCATION

The advantages that accrue from the use of harvest-aid chemicals cannot always be measured in dollars and cents. Some of the unmeasureables include ease of operating machines in defoliated fields and differences in wear and in machine life. Defoliated or desiccated fields also attract fewer mosquitoes and should therefore be more acceptable to hand pickers than undefoliated fields.

On Quality

Mature cotton picked from either spontaneously or artificially defoliated plants is usually higher in quality than mature cotton picked from undefoliated plants for at least two reasons. First, if at least 80 percent of the leaves drop during defoliation, which is considered acceptable under most conditions, there should be few green leaves to crush against the cotton and stain it during picking. Second, fewer leaf stalks, crushed leaves, and other debris should be in the picked cotton.

Field trials conducted in Mississippi, 1953 through 1955, substantiate the second statement. Weighted averages for the 3-year period showed a difference of 0.51 percent in trash content in favor of defoliation. This amounts to a little more than 2.5 pounds of trash per bale. Although this improvement is not enough to raise the quality of a bale of cotton from a given, absolute grade to the next higher grade, it could materially affect a bale that was marginal between grades.

Overall, the Mississippi trials showed that defoliating improved the quality of cotton in 14 of 18 cases studied. In 1954, under nearly ideal defoliation conditions, the estimated gain from defoliated plots amounted to $4.80 per bale.

Cotton defoliated prematurely, however, is another matter. Results from 12 tests conducted in 5 States over a 3-year period revealed that premature defoliation (when many late bolls were only partially developed): (1) Lowered the oil content of cottonseed, (2) increased fiber fineness and the incidence of neppiness in the carded yarn, (3) lowered

seed viability, (4) caused some decrease in yarn appearance grade, and (5) caused slight increase in picker and card waste. Premature defoliation did not significantly affect fiber length, skein strength of carded yarn, or protein content of seed.

Mature cotton picked from desiccated plants may escape being stained by green leaves, but it may contain significant amounts of dry leaf trash. For the latter reason, it may be lower in quality than mature cotton picked from defoliated plants.

At one time, the use of desiccants was discouraged because of the trash hazard and because it was thought that their use promoted the harvesting of immature cotton. It now appears that the latter assumption is most valid particularly when desiccants are applied at the wrong time. Faster-acting dessicants should be applied 5 to 7 days after the day when a defoliant would normally be applied. They should therefore contribute no more to the harvesting of immature cotton than properly applied defoliants.

On Yield

The effects of defoliation on yield is more difficult to evaluate than its effects on quality.

In theory, defoliation increases yields. One of the reasons given for the use of defoliants is the fact that the leaf fall induced exposes more of the bolls to sunlight and air, thus encouraging more of them to open. In rank, densely foliaged, heavily fruited cotton, the improved lighting and ventilation saves many bolls that would otherwise rot. The savings in some localities might be significant. In the vicinity of Florence, S. C., for example, it is not uncommon for boll rot to take 30 percent of the crop. During some seasons in the Florence area and in other areas of the humid Southeast, growth of rotting agents discolors almost every open boll in many fields. The cotton actually destroyed by boll rots averages about 192,000 bales a year.

During the 1954 and 1955 Mississippi trials, results showed that at 10 of the 11 locations studied over the 2-year period defoliation reduced yields. The reductions ranged from less than 20 pounds of seed cotton to about 50 pounds per acre; in only two instances did they exceed 50 pounds per acre. Average reductions were about 21 pounds per acre or about 3 percent. No attempts were made to interpret these reductions in terms of dollars and cents.

In these trials, defoliants were applied when the cotton was 60 percent open. Other, more recent trials indicate that yields are reduced less if defoliants are applied when more of the cotton is open. A general rule appears to emerge from these data--defoliation should be delayed until the cotton is at least 75 percent open. This rule-of-thumb, however, does not take in account other factors that might affect leaf fall and yield. Waiting until the desired 75 percent is attained might delay defoliation until fall rains and cool weather are imminent hazards in some localities.

Rain rapidly deteriorates unpicked cotton and cool weather limits the effectiveness of most defoliants.

Desiccating mature cotton should not decrease yield any more than defoliation. In fact, where defoliating attempts would obviously be unsuccessful because of late growth, second growth, or adverse weather, the use of desiccants may be the difference between some cotton harvested and no crop.

On Harvesting

Heavily leafed, succulent cotton plants cannot be efficiently picked by spindle machines because leaf juices clog the spindles and make it difficult to keep them clean. When most of the leaves are removed, however, the excessive-juice hazard is generally eliminated. In defoliated fields, the operator of the picker has a clear view of the cotton. He can keep his machine directly over the row and have no misgivings that he is missing a significant amount of cotton due to improper alignment of the machine with the row.

Severely lodged cotton is practically unharvestable, especially by machines. Sometimes the foliage is so tangled and matted that machines cannot effectively move through it. Defoliation or desiccation sometimes offers a solution to such problem growth. As the leaves fall or dry up, the lodged plants straighten up spontaneously, or are straightened by the machine as it moves through the field.

Hand pickers prefer to work in defoliated fields. In fact, defoliation is often done as a means of attracting them. The fact that defoliated fields are usually drier than undefoliated fields may add an hour or more to the picking day. It is generally conceded that after morning dew evaporates a relative humidity of approximately 50 percent is the dividing line between cotton dry enough to pick and cotton that is too wet. A 35-day experiment in one of the humid States revealed that the relative humidity in defoliated fields was less than 50 percent for an average of 7.6 hours a day compared with 6.7 hours in undefoliated fields. The gain in time because of defoliation benefited both hand and machine pickers.

Such gains in time can also be important in attaining an early harvest. Before the use of defoliants or desiccants became an established practice, cotton growers in some areas had to wait for frost to defoliate their cotton. In some years this meant a late harvest--sometimes the harvesting date was dangerously close to the time when heavy fall rains were imminent. Later harvests also delay fall seeding of a rotation or cover crop on the cotton land. Defoliants and desiccants have materially reduced these hazards. If conditions are favorable, growers can harvest relatively early and have their crop off the ground or seed a cover crop before bad weather sets in. They can sometimes time their harvests not only to outguess the weather hazard but to utilize available labor and equipment more efficiently than if harvest-aid chemicals were not used.

On Ginning

When mechanical cottonpickers first came into use, many gins had difficulty in processing the cotton they picked. The difficulties mostly centered around the fact that the cotton was trashy and moist. These conditions implied that the machines harvested too many leaves with the cotton and entered the fields when the cotton was too wet for ideal handling. Efforts to overcome these machine-picking shortcomings renewed interest in harvest-aid chemicals and accelerated their use and study.

Today, however, picking machines have been improved, the men who operate them are more experienced and skillful, and the gins have become more versatile and are better equipped to handle moist, trashy cotton. From the ginner's point of view, the need for defoliation or desiccation before harvest is therefore not so paramount today. However, production costs are higher for each added operation needed to prepare a harvest for the mills. Defoliation or desiccation might be cheaper in the long run if it eliminated some of the drying and cleaning operations.

On Fiber Quality

Whether a given harvest of cotton will make suitable yarn depends to a significant degree on its fiber length, fiber strength, and on its fineness as a factor of strength. Variety appears to be the dominant factor in predicting whether a given harvest of cotton has suitable fiber length, fiber strength, and fineness.

There is no evidence that defoliation or desiccation of mature cotton affects any of these characteristics. Fibrograph measurements of fiber length of undefoliated and defoliated cotton made during a 3-year period at seven locations failed to reveal any differences. Similar results were obtained when the Pressley Breaker was used to measure fiber strength. Micronaire readings for fineness under the same conditions showed no differences between undefoliated and defoliated cotton.

Overall, defoliated cotton is satisfactory and readily acceptable to millers. Spinners attest that defoliation does not influence the dyeing and bleaching of the mature cotton.

In other tests (11 tests in 5 States over a 3-year period), in which cotton was defoliated prematurely, the finer fibers obtained (because of immaturity) were not weaker or shorter. However, they had more neps, or tangles, per 100 inches of card web. If tested, they would probably have caused more "ends-down" (broken threads) in spinning. Fine fibers resulting from defoliating too early are thus undesirable. Because more and more cotton is being sold on a micronaire (measurement for fineness) basis, growers who harvest and market prematurely defoliated cotton will probably not get top price for their product.

On Insect Control

Defoliation's or desiccation's contribution to insect control is sometimes underemphasized. The following quotation is from a recent conference on cotton insect research and control:

"Chemical defoliation and desiccation of cotton aid in the control of many cotton insects. These practices check the growth of the plants and accelerate the opening of mature bolls, reducing the damage and the late-season build-up of boll weevils and pink bollworms which would otherwise remain to infest next year's crop. They also prevent or reduce damage to open cotton by heavy infestations of aphids, the cotton leafworm, and whiteflies. Stalks should be destroyed and other cultural practices followed . . . after harvest in areas where regrowth is likely to occur before frost or spring plowing.

"Defoliation or desiccation permits earlier harvesting and better use of mechanical harvesters. This also permits earlier destruction of the stalks, an important aid in the control of the pink bollworm and the boll weevil. However, if losses in yield and quality are to be avoided, defoliants and desiccants should not be applied until all bolls that are to be harvested are mature."

FACTORS THAT INFLUENCE EFFICIENT DEFOLIATION

The fact that a cotton plant has attained senescence does not mean that the application of a defoliant will result in adequate leaf fall. Other factors contribute to either satisfactory or unsatisfactory defoliation. Through proper management of these factors, growers can plan for efficient defoliation. They can manage cotton in such a manner that if and when defoliation is needed, the crop will be ready for it.

Stands

Any practice or condition that promotes good, uniform stands also promotes defoliation. Plants that make up uniform stands generally mature at the same time, which makes defoliation easier and more effective than if the stands were irregular. Level land that is adequately drained is a prime requisite. The density of plant is important but only within wide limits. The optimum number of plants per acre is usually dependent primarily on the soil type, the variety selected and the climate. Defoliation efficiency, however, is highly dependent on uniform stands which enhance uniform growth and maturity.

Planting uniformly viable seed at the right time and in properly prepared seed beds and uniformly applying fertilizer and insecticides at the right time are obvious but important factors to consider in the pursuit of uniform stands and uniform maturity of the crop.

Some of the conditions within an otherwise level and fertile field that interfere with the attainment of uniform stands are salinity and alkalinity, infertile areas, and sandy strips.

Leaching or the application of soil amendments or both during off seasons usually solve salinity-alkalinity problems, but neither will be effective unless the soil adequately drains.

Infertile areas may occur in any field--wherever the top soil has been removed or lost. Eroded areas, where leveling for drainage has removed too much top soil, or spoil bank redistribution are sources. Reclamation usually includes liming to correct acidity and heavy fertilizer application to correct low fertility.

Sandy strips usually do not retain enough water and nutrients during a season for consistent plant growth. Organic matter such as manure and crop residues, generously applied, may improve some of them.

Plant Condition

The manner in which a cotton plant grows affects the manner in which it will defoliate. Plants that initially start off well in the spring, when moisture and nutrients are ample, and then encounter drought or an insufficiency of nutrients, may have a poor growth history in terms of their ability to defoliate. Mature foliage on such plants resists the action of defoliants. Succulent foliage that later develops under improved conditions also resists the action of defoliants because it is not mature enough to have developed abscission zones.

Plants grown under droughty, bright, hot conditions, especially where winds are persistent, have tough leaves that resist the penetration of defoliants and thus reduce the amount of defoliant that can actually react with the cell contents of the leaves. In contrast, plants that have grown luxuriously and have more tender leaf surfaces and more moisture usually respond to defoliants and abscise promptly.

Insect Control

Besides destroying significant amounts of marketable cotton, severe insect attacks can also deform a cotton plant and make its defoliation difficult, particularly if early insect attacks kill terminal buds and cause abnormal, bunchy growth. The deleterious effects often arise because the insects destroy the early bolls and much of the plant's reserves then goes into vegetative growth rather than fruiting. With this delay in fruit set the leaves may retain their physiological immaturity until it is too late in the season to apply defoliants. Excessive growth also causes plants to lodge and lodged plants cannot always be defoliated efficiently unless defoliants are applied more than once. Repeated applications may be prohibitively expensive in some years.

Weeds

Any extracurricular growth in a cotton field may compete seriously with the cotton for water and nutrients. As a consequence, yields may be reduced before defoliation is attempted. Surviving plants may be too stunted or too desiccated to respond to defoliants.

Excessive and vigorous growths are not usually affected by defoliating chemicals. Consequently, they may interfere with machine harvesting and may be sources of trash and stain--particularly bad are grasses because they cannot be easily removed either at the gin or in the spinning mill.

It is sometimes extremely difficult to cover a leaf when it is shielded by such growth. Even repeated applications may fail and may do more harm than if defoliation was not attempted at all. The reason is that some leaves receive too much defoliant and so may be quickly killed and ultimately retained firmly on the plant instead of abscissing, which they should do under proper conditions and correct dosages.

Irrigation and Fertilizer

The expression "just enough" aptly applies to the use of irrigation and fertilizer to condition crops for defoliation.

Cotton, like many other plants, needs a consistent, adequate supply of moisture during its growing and fruiting life to maintain uniform growth. Delaying a single irrigation may stress the plants and lead to unsatisfactory results when defoliation is attempted. In California, for example, investigators learned that cotton that had adequate moisture throughout the season was 11 inches shorter and less rank than cotton given no irrigation until about 11 weeks after planting. In South Carolina, yields of cotton were increased 655 pounds per acre by two irrigations totaling but 2.6 inches. But, more pertinently, the same experiments revealed that irrigated cotton defoliated more effectively than unirrigated cotton because less second growth occurred on the irrigated cotton after late summer or early fall rains.

Careful timing of the last irrigation in either the West or the humid East is perhaps the most important irrigation factor affecting defoliation. Water added after cut-out (when plants stop growing vegetatively and rapidly shed blooms, squares, and small bolls) does not increase yields. Instead it makes plants tall and leafy--good candidates for lodging and matted growth.

Significant amounts of water in the soil after defoliation may be used by the plants to initiate second growth. The plants, however, need some water at defoliation time if they are to abscise properly since abscission is a vital process. Determining exactly how much water to apply at the last irrigation is therefore a critical problem for most cotton growers who irrigate and who find that defoliation is necessary. Local recommendations cannot always be followed because soil types and growing

conditions often vary even in adjacent fields. It is usually recommended that growers determine how much water their cotton is using each day and how many inches of water per foot their soil retains. If they integrate with this data the results of past seasons, the water-need estimate at the last irrigation (with some left over to support abscission) ought to be fairly accurate.

Fertilizer management is also a critical problem. If too little is applied before or during the growing season, its effects may be negligible and the applications more or less wasted. If too much is applied, however, especially nitrogen, plants may feed on the excess after defoliation and inevitably produce second growth. Nutrients therefore should be just about exhausted at defoliation time. The just-about qualification means that enough is available to support boll maturity and abscission but not enough to support second growth. It is usually recommended that nitrogen be applied in one increment at or near seeding time. In California experiments, up to 150 units of nitrogen, applied at seeding time, were nearly exhausted at the desired time in relation to the last irrigation. Tender growth was largely eliminated and the likelihood of second growth was reduced.

Other nutrients that affect the growth of cotton and indirectly affect its defoliation are calcium and potassium. A calcium deficiency often shows up in rank vegetative growth and delayed fruiting. A soil deficient in potassium produces cotton plants that lose many of their leaves before bolls mature. The need for artificially defoliating such plants may be reduced but so are cotton yields from them.

Topping

A cotton plant is a monopodium, its main stock has a dominant growing point (a terminal bud) at the apex or top. If the plant grows too high, it is sometimes feasible to retard its growth by cutting off the terminal bud and thereby reduce its tendency to lodge. The cutting-off is called topping.

In areas where high yields are often accompanied by excessive and unmanageable growth, topping is now being investigated intensively as a means of insuring quality and of increasing defoliant efficiency and thereby reducing harvesting difficulties. Other investigations are under way with chemicals that could conceivably depress terminal growth without reducing yields and thus improve defoliability and harvesting efficiency. Also under investigation is vertical topping--cutting a narrow vertical path down the middle of overlapped rows to let sunlight and air penetrate to the lower branches.

Experimental results so far indicate that topping is a precision practice. insofar as proper timing is concerned. If done too soon, lateral branching may be excessive and yields reduced. For example, topping plants (which would normally grow to 5 feet or more) at the 4-foot height, has proved beneficial in the Far West but it is not known if this 4-foot height is ideal for topping elsewhere in the belt. Investigations now under way will do much to aid the grower in determining the ideal time and the

proper techniques to use in topping cotton plants where and when the need is evident.

Topping tall plants by hand was a common practice in California 10 to 15 years ago. Tests conducted in the Far West since 1951, however, show that machine topping is effective and that lodging of machine-topped plants is retarded without reducing yield. Several types of satisfactory machines have been developed.

Temperature and Humidity

Since abscission is a vital process, the best leaf fall results from defoliants when temperatures are high. When maximum daily temperatures average below 60°F., defoliation becomes very difficult. On the other hand, if temperatures are consistently high (above 100°F.), cotton leaves may lose so much moisture through transpiration that they become too dry to respond to defoliants. Between these extremes, 60°F. and 100°F., each 10° decrease in temperature doubles the time required for leaf fall.

The amount of moisture in the atmosphere influences the rate of defoliation. Plants growing under humid conditions usually retain more internal moisture than plants growing under arid conditions because evaporation rates are correspondingly lower. Internal moisture is of course needed to promote the absorption of defoliants and to insure that abscission occurs promptly. Less evaporation also means that the defoliant is retained as a liquid on the leaf longer. This is extremely important because defoliants do not react with a leaf unless they are applied as liquids or become liquid on the leaf. And the longer the defoliant retains its liquid or moist state on a leaf, the more efficient it is. Defoliant dusts are not fully effective unless the leaf is wet with dew.

Leaf Coverage

Defoliation will not be complete unless every leaf on the plant is thoroughly covered with the defoliation agent because most chemical defoliants are not systemic in their action--they do not absorb at one point on the plant but react at another. (However, if they were systemic, adequate leaf coverage would still be desirable.)

If dust defoliants are used, the dust should be applied in such a manner that every leaf receives a thin, uniform layer. If sprays are used, each leaf should still receive adequate coverage, but relatively large droplets that actually flow to some extent on the leaf are more effective than numerous fine, pinpoint droplets. A thoroughly wet leaf is the optimum desirable, but spraying to the point of runoff is usually too expensive, especially where the plants are large and leafy.

Many experimental results are on record that emphasize the need for thorough leaf coverage. An Arkansas experimenter, for example,

treated different portions of the upper surface of mature leaves with an efficient defoliant. He obtained the greatest response (leaf fall measured against time) by treating the entire surface and progressively less response when three-quarters, one-half, and one-fourth of the leaf surface was treated. A greater response also resulted from treating the lower (under) surface than from treating the upper surface. This was explained by the fact that the lower surface was less exposed and weathered and therefore less tough than the upper surface. Other experiments revealed that a defoliant applied to both blade and petiole shortened the time of abscission as compared with blade applications only. But the rate was extremely slow when the defoliant was applied only to the petiole. The petiole-only results seem to establish the fact that leaf-blade coverage is the prime initiator of abscission.

LATE GROWTH

Late growth appears to be one of the most pressing problems facing cotton researchers. The problem arises from the fact that some growers, striving for ultimate yields, fail to appreciate that most yields above 2 bales per acre come from late growth and that defoliation and harvesting problems increase with late growth.

If growers fertilize and irrigate for 1 bale plus per acre, they usually have no defoliation problems because their crops and leaves mature while the weather is favorable for defoliation. They can usually defoliate successfully and then have ample time for quality machine harvesting. If they manage their fertilizer and irrigations carefully, no postdefoliation, preharvest problems should emerge.

However, if growers continue to add fertilizer and continue to apply irrigations in the hope of getting 2 or 3 bales per acre, they may be inviting defoliation and harvesting problems--particularly in humid areas. Under such practices, late growth is inevitable and late growth usually means dense, immature foliage, late insect control problems, deterioration of lower bolls, and ultimate lodging. As harvesttime approaches, growers who attempt to defoliate such growth are usually disappointed. Repeated applications may not remove all the leaves because (1) many of the leaves are juvenile, (2) growth is so massed that many of the leaves cannot be reached by the applicator, and (3) other factors such as lateness of season and cool weather may make efficient defoliation difficult or even impossible. Many times such late-growth plants are not ready for harvest until a desiccant is applied to dry up the juvenile and the inaccessible leaves and thus to induce the plants to straighten up so the harvesters can see where the rows are.

If defoliants were ideally efficient, there would, of course, be no problem. But until more efficient defoliants are developed, growers will probably find it practical to use desiccants on late growth and to remember that the use of desiccants has some disadvantages--none of which, however, are as serious as harvesting no cotton at all.

Many growers, who have gone through the late-growth problem, have decided that the returns are not worth the effort. They usually found it

necessary to spend more for fertilizer and to use up more of their time irrigating. And often, more insecticide applications are required. They then had to fight the defoliation difficulties, which were usually resolved by applying two or three partially effective doses of defoliant followed by desiccation. The repeated applications added to production costs. As a climax, the growers usually harvested a lower grade of cotton than they would have under different management.

Growers can hardly be blamed for trying to make the best use of their land and resources. Nonetheless, they should be encouraged to draw the line somewhere and not to strive for ultimate yields until research has an opportunity to wrestle more with this problem. A recent research approach is discussed on page 10 under Topping.

SECOND GROWTH

The fact that cotton is inherently perennial means that it can often complete one cycle of growth during a season and start another. This phenomenon is called second growth. If it occurs after defoliation and before harvest, it can be extremely inconvenient--even disastrous, perhaps--because it defeats defoliation two ways: (1) It is green, succulent, and staining like the leaves that were initially abscissed; and (2) it does not respond to routine defoliation because it is juvenile and therefore the leaves are minus differentiated abscission zones. Many growers consider second growth today's most difficult cotton-harvesting problem.

Defoliation appears to accelerate second growth because when leaves are removed, the plant's energy goes into the new growth. This fact implies that growing conditions have to be favorable, especially that the plant has enough nutrients and moisture. It also suggests that second growth can be controlled by proper management of fertilizer and moisture in the manner already described. But preventive control, while being something to aim for, is not always attainable because too many factors cannot be controlled--rain, for example, or the understandable lack of refinement in fertilizer-need determinations.

Second growth almost never begins until after a crop of bolls are about mature. Thus it usually occurs at the end of the season. But it can happen several times during a season where determinate varieties tend to cut-out during droughts and then later resume growth and flowering.

At one time, growers could do three things. They could (1) kill the leaves after regrowth by using a recommended desiccant, (2) kill the plant before second growth (at least kill all buds and growing points), and (3) use a chemical that retards second growth without killing the plant.

Pentachlorophenol is the only chemical at this time that is a recommended[1] desiccant used as a killer of cotton plants. Adding 2, 4-D or 2, 4, 5-T or both to it almost guarantees that it will efficiently kill and thus

[1] Certain other desiccants are recommended for use within given States. Only pentachlorophenol is recommended in all cotton States. See footnote, page 17.

exclude second growth. But this procedure may not be as simple as it appears. Research has not, as yet, investigated all the ands and buts associated with killing cotton plants before harvest. Killing stops growth immediately, could contribute to the harvesting of immature cotton, and could in fact decrease yield, if used without proper precautions. Where cotton is machine stripped, for example, chemically killed plants may dry out rapidly and the boll stalks (pedicles) may degenerate so quickly that machines knock the bolls to the ground before they come in contact with the harvesting rollers. When 2, 4-D is used on cotton, the seed cannot be used for planting.

Maleic hydrazide and amino triazole are the only chemicals so far discovered that may inhibit second growth long enough (up to 6 weeks) to permit complete harvest after defoliation. But both now appear to be also-rans. Maleic hydrazide was never fully offered commercially--it was sold for use on cotton only under an experimental label. Amino triazole was never universally satisfactory because it was expensive and the high rates needed to be effective in most parts of the Cotton Belt frequently made its use uneconomical. Despite these limitations, amino triazole was the best second-growth inhibitor ever used on cotton. It will probably not be available commercially for use on cotton after 1959.

The chemical control of second growth, then, is apparently narrowed to the use of desiccants at this time, or until research can find a reasonable solution to this problem. This emphasizes the need for growers to manage their cotton so second growth will be unlikely. If second growth develops before defoliation it usually necessitates desiccation. Although desiccants usually kill this predefoliation growth, neither type chemical fully prevents second growth when plant and weather conditions are favorable.

TIMING OF DEFOLIATION

Assuming that all the factors affecting efficient defoliation have been considered and that a given grower decides that his crop is defoliable--when should he start? Generally speaking, the answer is about 2 to 3 weeks after cut-out, if his type plants cut-out. The cut-out point is reached when the drain of maturing bolls causes the plants to stop vegetative growth. As it approaches and as fruiting and boll maturity progress, more and more leaves become senescent and defoliable in the vicinity of the maturing bolls. They will then abscise (assuming that other factors are favorable) if treated with an efficient defoliant. A reasonable possibility should also exist that postapplication weather will be clear[2] and harvesting should begin about 10 days after defoliant application.

Maturity is the state of being ripe or fully developed. Cotton bolls usually attain maturity (insofar as freedom from injury through defoliation is concerned) when they are 35 to 42 days old, that is, 35 to 42 days from the time of open bloom. The overall age of the plant or a date on the calendar may be poor guides to boll maturity. Some rules-of-thumb,

[2] Through the cooperation of agricultural leaders in some States, the U. S. Weather Bureau makes specialized weather forecasts during the defoliation season.

however, have been developed: Mature bolls feel firm (cannot be dented) when pressed between thumb and forefinger; they cannot be sliced easily with a sharp knife. The fiber in mature bolls is also said "to string" when the boll is cut. Boll maturity can also be estimated by relating it to seed maturity. If the embryo in a cut seed completely fills the seed cavity, the seed (and therefore the bolls) are mature.

Cotton plants, however, do not always cut-out. Sometimes in some sections of the Cotton Belt they continue to set bolls and to grow vegetatively until frost. Deciding when to initiate defoliation on such plants is difficult. Starting defoliation prematurely means that some of the bolls on the top of the plants will be lost, or at least that the cotton harvested from them will be inferior in grade and yield. Delaying defoliation, however, until these top bolls mature means a later harvest and more likelihood that the lower bolls will rot. The grower has to decide whether his top crop is better than his botton crop or if it is feasible to attempt to save both by defoliating each separately. The last possibility is not worth considering unless the cotton is heavily foliaged and heavily fruited. In any event, defoliation is not started until the bolls selected are mature.

Other considerations might influence a grower's decision about when to defoliate, however, especially if he plans to utilize custom (usually airplane) applications. (About 64 percent of the harvest-aid chemicals used on cotton in 1958 were applied by air). The contractor usually helps the grower decide how much of which chemical is to be used, but the grower himself has to decide when.

If machine harvesters will not be continuously available after defoliation, the grower might have to defoliate some of his crop earlier than he would like to and some of it later. And, since defoliation sometimes promotes second growth, defoliating at one time his entire crop, which might take a month to harvest, might be a mistake. But, if bottom bolls are rotting, he has to get rid of the leaves to promote drying. He should not, however, defoliate as a means of promoting boll maturity because harvest-aid chemicals do <u>not</u> hasten maturity--they only hasten drying and opening if drying weather prevails.

Many growers in the Southeast in the fully mechanized areas have adopted the practice of planting two varieties that yield about the same amount of high-quality cotton. One of the varieties matures earlier than the other. As the earlier one matures, it can be defoliated and harvested. During the initial harvesting interval, the other variety will probably be coming into maturity. The processes are then repeated. This practice may eliminate the need for defoliation based on a compromise and lead to a more methodical harvest.

BOTTOM DEFOLIATION

Bottom defoliation has limited advantages in many areas of the Cotton Belt. It has proven to be useful and profitable in the West, but in the East, its usefulness is still subject to further evaluation. Where 2 to 3 bales per acre occur in the East, bottom defoliation does not always reduce boll rot even when it tends to reduce lodging. Following bottom

defoliation in such eastern cotton, and especially after late rains or irrigations, the canopy of leaves may close in higher on the plants and create near the ground a perfect moist chamber for development of boll-rotting organisms.

When bottom defoliation is being done, extra care is needed to see that the defoliant does not penetrate too high on the plant. The spray pattern should be directed only toward the mature bolls in the lower part of the plant. If the spray covers leaves near the immature bolls or squares, the youngest bolls and squares may shed excessively and the treatment may damage fiber and seed of other immature bolls. Experimental yield losses chargeable to misdirected spray have reportedly run as high as 52 percent.

Bottom defoliation is usually done at a time when plant activity is high and the bottom leaves are mature. Consequently, good leaf fall usually results--if the defoliant is placed correctly. Besides reducing boll rot under some conditions, bottom defoliation may: Accelerate mature boll opening, reduce lodging, and eliminate the need for more than one application in rank cotton. It sometimes further serves as a partial control of grass and weeds--as a substitute for late cultivation.

ADDITIVES

The group of chemicals variously referred to as spreaders, stickers, activators, wetting agents, and surfactants (surface active agents) are considered here as additives--compounds which are added to harvest-aid chemicals to improve their effectiveness. Their use with spray defoliants is worthwhile if growers are forced to defoliate when conditions are not favorable. In Arizona, field and greenhouse experiments that compared defoliant-additive mixtures against defoliants only confirmed this fact. The unfavorable conditions listed were excess nitrogen; leaves wilted, toughened, and inactive; leaves and bolls immature; second growth; and low temperatures, which ranged from 42° to 75° F. Increase in leaf fall from the use of additives ranged from 5 to 30 percent; maximum leaf fall occurred 4 days earlier.

Under favorable conditions for defoliation (low nitrogen, mature leaves and bolls, high temperatures, and no moisture stress) the gain in leaf fall from the use of additives was not significant. Usually it was about 5 percent; maximum defoliation was said to have occurred 3 days earlier.

The additives apparently increased the incidence of second growth defoliation but the increase was not significant. The maximum recorded in any experiment was 15 percent.

The additive should be one recommended by the particular manufacturer of the defoliant used. Soap chips or washday detergents are not desirable. Some additives may clog the nozzles of sprayers or cause excessive foam in spray tanks.

Establishing the absolute need for additives is difficult even for an expert. Consequently, growers should consider their use as a form of

insurance for which the premiums are low--low because these compounds do not harm even when they are not needed.

THE CHEMICALS[3]

Hundreds of private, public, and commercial research workers have screened thousands of chemicals in the search for efficient defoliants, desiccants, and second-growth inhibitors. Of the thousands, only about 14 have ever been recommended by public service agencies and of the 14, only 6 are now extensively used. These 6 are discussed below.

Calcium cyanamide.--This chemical's defoliation ability was discovered accidentally in the late 1930's when some of it (being used as a fertilizer) drifted onto mature, dew-wet cotton leaves. It was the only cotton defoliant available commercially until 1948. It is now marketed only as a dust, which usually contains about 57 percent calcium cyanamide. The dust is easily distributed over the leaves of even the most rank cotton, but requires 2 to 4 hours hydrolysis on the leaf for maximum activity. Where dews are adequate, it is an effective, economical defoliant; when and where dews are inadequate, it is not effective.

Calcium cyanamide and other dust defoliants should be applied only when the air is calm to make certain that the material is evenly distributed over the field and to minimize drift onto nontolerant crops like soybeans or onto immature cotton.

Sodium chlorate-borate mixtures.--The active ingredient of these mixtures is sodium chlorate. Borate salts are used as fire retardants. Their introduction gave growers by 1950 the advantages of having both dust and spray defoliants. The mixtures range in percent of active ingredient from 18.2 (where merchandised as a liquid concentrate) to 60 (where sold in granular form) and for the most part all are formulated with sodium metaborate. All are equally efficient when applied at equivalent rates of sodium chlorate.

Limited quantities of a hygroscopic sodium chlorate-borate dust defoliant have been offered commercially. It needs less leaf surface moisture than calcium cyanamide for initial activation, but generally speaking, it is about equally dependent on dew for highest efficiency. Currently, its use is limited.

Magnesium chlorate.--This chemical was first offered commercially for use as a cotton defoliant in 1952. Currently it is available as magnesium chlorate hexahydrate and as magnesium chloride-sodium chlorate, which are mixed together in aqueous solution, to form magnesium chlorate hexahydrate. In either formulation, the magnesium chlorate is hygroscopic and thereby offers its own fire retardant properties. Currently there are at least three commercial variants labeled magnesium chlorate and four or more that list a mixture of magnesium chloride with

[3] The listing of specific harvest-aid chemicals in this report is not to be considered as a recommendation by the United States Department of Agriculture unless all requirements of the Pesticide Act (Public Law 518), and the recent amendment to this act (Public Law 86-139) as it applies to Section 408 of the Federal Food, Drug, and Cosmetic Act, are met.

sodium chlorate. From the standpoint of defoliation there is little or no difference between the two types. Efficiency depends entirely on the percent of magnesium chlorate hexahydrate present in the preparation.

All of these are slightly more herbicidal than the sodium chlorate defoliants and are thus preferred where foliage is tough and more leaf surface activity is required. Under ideal conditions, there is little if any choice among all the chlorate defoliants if compared on an equivalent active ingredient basis. As with the sodium chlorate group, some of the magnesium formulations are merchandised as dry salts, others as liquid concentrates.

Amino triazole (AT).--This chemical was marketed in 1955 after extensive experimentation by State and Federal workers.

As previously mentioned, AT was the only chemical ever widely recommended to control second growth in cotton. It also improved the efficiency of other defoliants when they were mixed with AT, sometimes cutting in half the amount of supplementary defoliant needed.

AT worked best in the East where high relative humidity aided its activity. In the West rates two to three times those effective in the East were needed and hence it was not popular in arid parts of the Cotton Belt.

Organic phosphorus compounds (s,s,s,-tributylphosphorotrithioite and s,s,s,-tributylphosphorotrithioate).--These chemicals were both introduced as spray formulations in 1957 after extensive experimental trial. They appear to have systemic properties. They are highly efficient and induce the most rapid leaf fall of any defoliant. They often remove immature leaves and sometimes they partially defoliate the older leaves of second growth. They are effective at low concentrations of active ingredient.

Pentachlorophenol.--This chemical was sold to growers and aerial applicators as a "cotton defoliant" before government scientists had an opportunity to conduct the investigations that resulted in its present designation as a "desiccant" or "crop dryer." It is usually applied in oil (diesel fuel or kerosene) or in an oil-water emulsion. Since these oils are also herbicidal, the treatment kills all cells upon contact and permits the affected parts to dry out rapidly. Most often the kill is so rapid that an abscission response is impossible. The dried leaves, however, become brittle and may eventually snap or break off, either partly or entirely. Pentachlorophenol stops growth almost immediately and consequently should not be used, except as an emergency measure, until all the bolls are mature and 80 to 90 percent are open.

REGIONAL CONSIDERATIONS

When defoliants are being discussed, it is considered convenient to list three cotton-growing regions and these are the humid South, the semiarid Southwest, and the irrigated West.

This region includes the States and parts of States where cotton is grown from east Texas and Oklahoma to the Atlantic Ocean. It comprises the areas formerly referred to as the Midsouth and Southeast. This is a region where rainfall is normally high, but where late summer droughts are not uncommon and where late rains (late August for the coastal plains of Georgia to November for southern Missouri and northern Arkansas) are almost certain to occur. As fall approaches in this region, and the weather becomes cooler, defoliation becomes more difficult. In Mississippi, for example, one of the most southerly States, it has been statistically established that night temperatures between October 10 and October 23 will be too low for efficient defoliation at least 50 percent of the time.

In the humid South, long-stapled cotton (1 to 1-1/16 inch $\pm$ 1/32 inch) is usually grown and harvesting is done by either handpickers or by spindle-type machines. Some degree of defoliation (either natural or induced) is usually desirable at harvest time.

Need for Chemical Defoliation

In the hill lands and in much of the coastal plains of this region, the soil is sandy and poor. Nutrients are usually exhausted at the end of the season and extensive natural defoliation may occur, especially when drought and cool weather combine with nutrient deficiency to promote senescence and activate abscission. Chemical defoliation at such times is unnecessary and uneconomical. Even in rich, alluvial soils, when plants are mature and fully cut-out and when leaves are leathery rather than tender, defoliation for spindle picking may be unnecessary--if harvesting can be done before second growth, if wet weather is not imminent, and if lodging does not occur. But yields of 2 bales plus per acre can seldom be harvested efficiently without some chemical defoliation.

Recommended Practices

To adequately control the growth of any adapted variety in the humid South, insect control must be timely, fertilizer needs must be calculated carefully, and the crop must be irrigated when it needs water. If these practices are followed, the plants will cut-out when the crop matures. Defoliation at this time should be efficient and complete because the plants are physiologically mature and the weather is still favorable for high plant activity. If these objectives are attained (complete cut-out and efficient defoliation), no attempt should be needed to save the elusive top crop. Growers who attain successful defoliation usually have their crops ready for harvesting before boll rot becomes a problem, if the weather is favorable.

If second growth now occurs before harvest, it should be no more of a problem than if the initial defoliation had been delayed. It can usually

be handled by desiccating the few new and immature leaves that appear and thus keep the crop ready for clean picking--from a grade standpoint, a little dry trash is better than risking stain (see section "On Ginning," page 6).

Growers who fail to achieve cut-out or uniform maturity may be faced with a difficult decision--is it better to save the top crop or the bottom crop? If bottom defoliation is tried, the open bolls are still vulnerable to bad weather (unless they are harvested) while the top bolls are maturing. (Sometimes it is possible to remove two to five spindles from a mechanical picker and replace them with plugs and subsequently pick the bottom bolls without damaging the top crop of green, unopened bolls.)

The Semiarid Southwest

This cotton-growing region is the western part of Texas and Oklahoma. Only about 20 inches of rain falls in a year. Cotton is usually grown on residual winter moisture plus the scanty rainfall that occurs during the growing season. More and more growers, however, are turning to irrigation.

The growing season in this semiarid region is shorter than in any other cotton-growing region in the United States, presumably because of higher altitudes, which range up to 4,000 feet. High winds frequently occur during the growing season; heavy rains occasionally fall.

Two types of cotton are grown--the fluffy-bolled eastern and the so-called "storm-proof" in which the lint is held tightly in bolls that do not open fully even when the bolls are mature. The latter type is less easily damaged by the high winds and heavy rains.

Harvesting practices are geared to the storm-proof type, but the cotton is not actually picked. The bolls are snapped or broken off either by hand or by machines (called strippers), and burrs and other trash are included in the harvested cotton and go along with it to the gin. If the trash is dry, no problems exist because the gins are equipped to remove trash and because this storm-proof cotton is short-stapled (7/8 inch to 1 inch) and coarse--tough enough to withstand vigorous ginning. Problems may appear when eastern-type cotton is harvested by strippers.

Need for Leaf Conditioning

Wherever cotton is harvested by strippers, complete removal or drying of leaves by defoliation, desiccation, or frost is mandatory for satisfactory results. But complete defoliation in the semiarid Southwest is often difficult, and consequently desiccants have to be used extensively if stripping is to be done before frost. Tests made at Lubbock, Tex., showed no quality damage from desiccants applied to mature, dryland cotton on October 3, which is about a month before the normal frost date.

The main advantage derived from desiccation appears to be an earlier harvest. When irrigation is practiced, or when cotton matures late, growers in this region may not find it economical to defoliate or desiccate and harvest before frost.

Recommended Practices

Because of the short growing season, most growers favor determinate, quick-maturing varieties. Consequently, if conditions are favorable after these varieties cut-out, second growth may occur and may be more than an inconvenience--green leaves in stripper-harvested cotton present a real hazard to efficient processing. Where desiccation is employed extensively (for example, throughout central Texas), second growth is a particular hazard, and particularly vigorous methods are sometimes needed to forestall it. One such method is adding 2,4-D or 2,4,5-T to pentachlorophenol desiccant in the manner previously described. (Growers who use this combination should be aware that 2,4-D affects the viability of seeds.)

Growers in this region can advantageously follow other practices in some years. They can double harvest, for example, hand-pulling early bolls, which often produce high-grade cotton, and later machine-strip. They can sometimes defoliate to attract hand pickers and later desiccate for the final stripping, but both practices should be done judiciously or little net benefit will be realized.

The Irrigated West

This region includes Arizona, California, Nevada, New Mexico, and where cotton is fully irrigated in the El Paso areas and in the Pecos and lower Rio Grande Valleys of Texas. Except for the higher elevations of West Texas and New Mexico, this region has the longest growing season in the Cotton Belt. Late fall rains are not usually hazards.

Cotton grown is the open-boll type, either Acala or eastern varieties--consequently, it is picked and not stripped. Except near the Mexican Border, where handpickers have been available, machine picking predominates. Yields are high, approaching an average of 2 bales per acre or better in most years, and the accompanying plant growth and leaf cover are also high.

In this western region, leaves are consistently tougher than leaves farther East, which usually means that more defoliant has to be used. The difference in degree of toughness is due somewhat to variety but more often to the fact that atmospheric moisture is always correspondingly low.

Need for Defoliation

Handpicking is sometimes done without chemical defoliation, but not machine picking. When lodging occurs, it is a serious harvesting problem, often calling for two or three applications of defoliants.

Recommended Practices

Varieties are bred to utilize the full season and to maintain a vigorous balance between vegetative growth and fruit development until the end of the season. Consequently growers may have trouble with late-season, immature leaves unless they "manage for harvest." The managing includes the careful regulation of water and fertilizer as already described--i.e., metering fertilizer so it will be exhausted at the proper time; regulating water so plants do not grow too rank; and terminating irrigation in time to permit full maturity of bolls before temperatures are too low for efficient defoliation. If these objectives are attained, growers must then use all their skill to schedule defoliation late enough so boll maturity is not interrupted but early enough to insure that the plants have sufficient moisture to support abscission. Scheduling decisions should also be guided by the fact that, on the lighter soils, fully irrigated plants seem to dry out unusually fast and speedily to approach the state of permanent wilt and full desiccation when irrigations are terminated.

If irrigations are handled in the manner described, second growth is usually not a problem.

Exceptions to this general pattern occur in the lower valleys of California, the high elevations in New Mexico and West Texas, and in the lower Rio Grande Valley. In the Imperial Valley, for example, two 1- to 1-1/2-bale crops are grown on the same plants each season--the double cropping made possible by a midseason cut-out. The first crop is almost universally handpicked. The second crop may be handpicked but machine picking after defoliation appears to be increasing.

In West Texas and New Mexico, the season is relatively short and if handpickers are available growers may not find it advisable to manage for early maturity or to defoliate too early when the top crop may be immature. The fact that the number of handpickers is rapidly declining, however, may force these growers to manage for harvest and to use chemicals before machine picking.

In the lower Rio Grande Valley, the mandatory plow-up date for pink bollworm control influences the scheduling of defoliation more than any other consideration. Nonetheless, growers are finding that it is possible to manage for harvest and to time defoliation for the most beneficial results well before the mandatory plow-up date. Such management is usually successful unless the crop is late and speedy harvest before the plow-up date cannot be avoided.

* U.S. GOVERNMENT PRINTING OFFICE : 1960 O—554082